

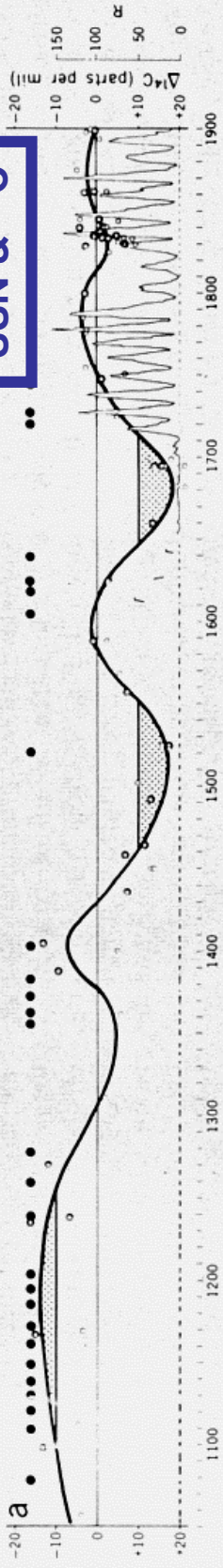
# The Solar Wind During Grand Minima

[ ]  
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Easy Tool Kit, Inc.

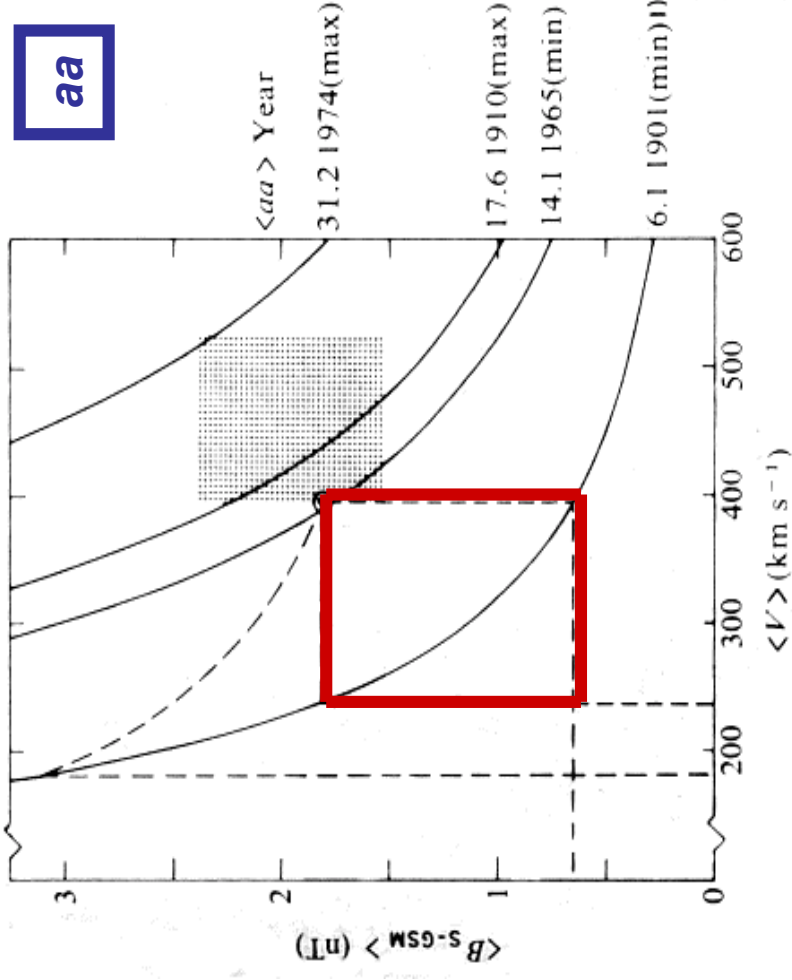
# Outline

- History
- ~ 130 Years of Solar Wind
  - Solar Wind Speed (IDV)
  - Interplanetary Magnetic Field (IDV & IHV)
- Extrapolation to the Maunder Minimum via SSN
- Consistency Checks via  $^{10}\text{Be}$  &  $^{14}\text{C}$
- Conclusion

SSN &  $^{14}\text{C}$



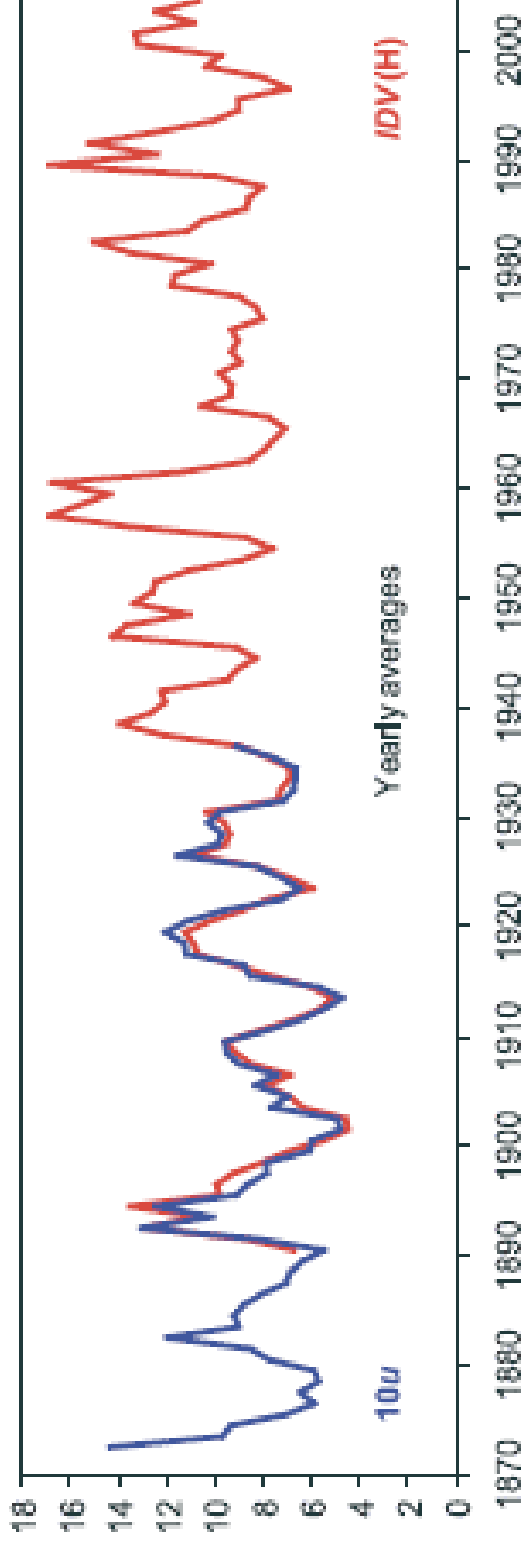
Jack Eddy



aa

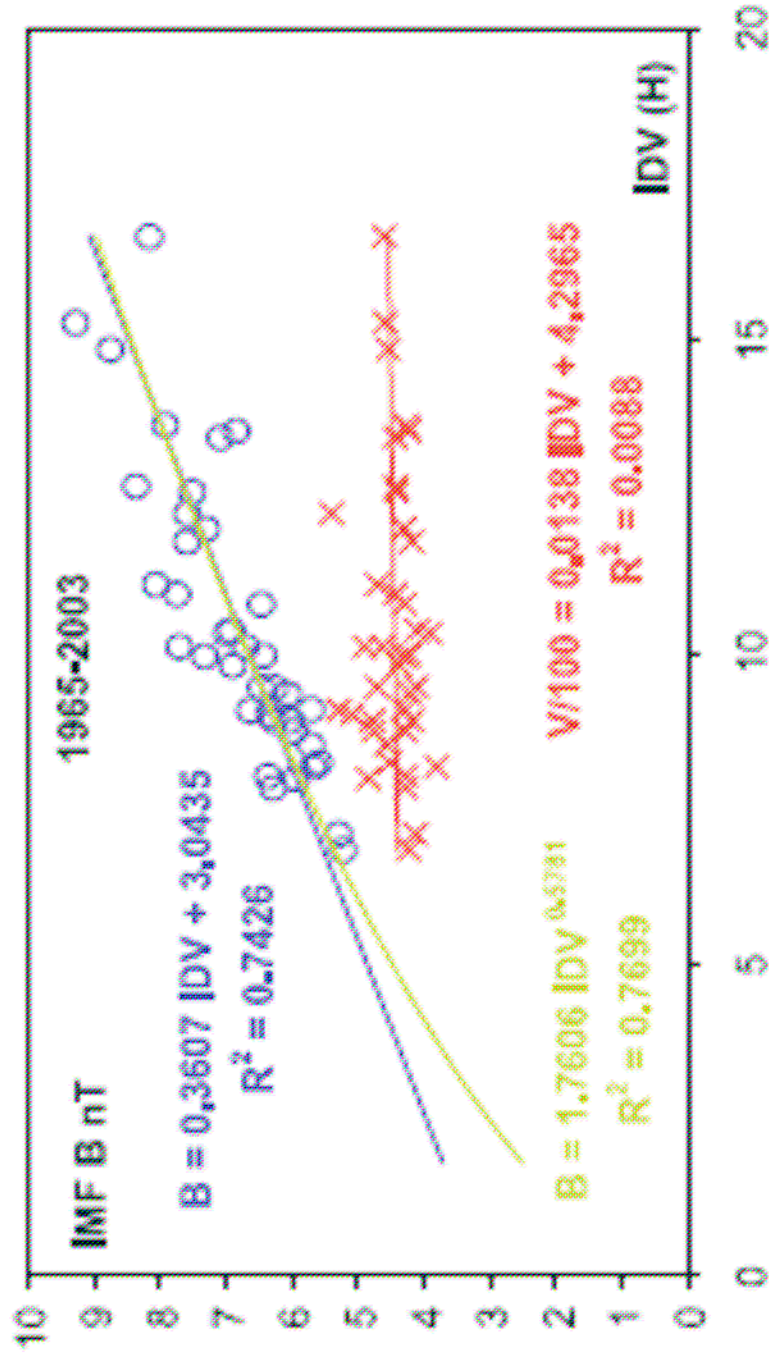
# Interdiurnal Variability (*IDV*) Index

- Based on Bartel's  $u$ -index
- Average of absolute values of differences between H-component measured at midnight on consecutive days for mid-latitude stations
- Time resolution = 1-year
- Available since 1872

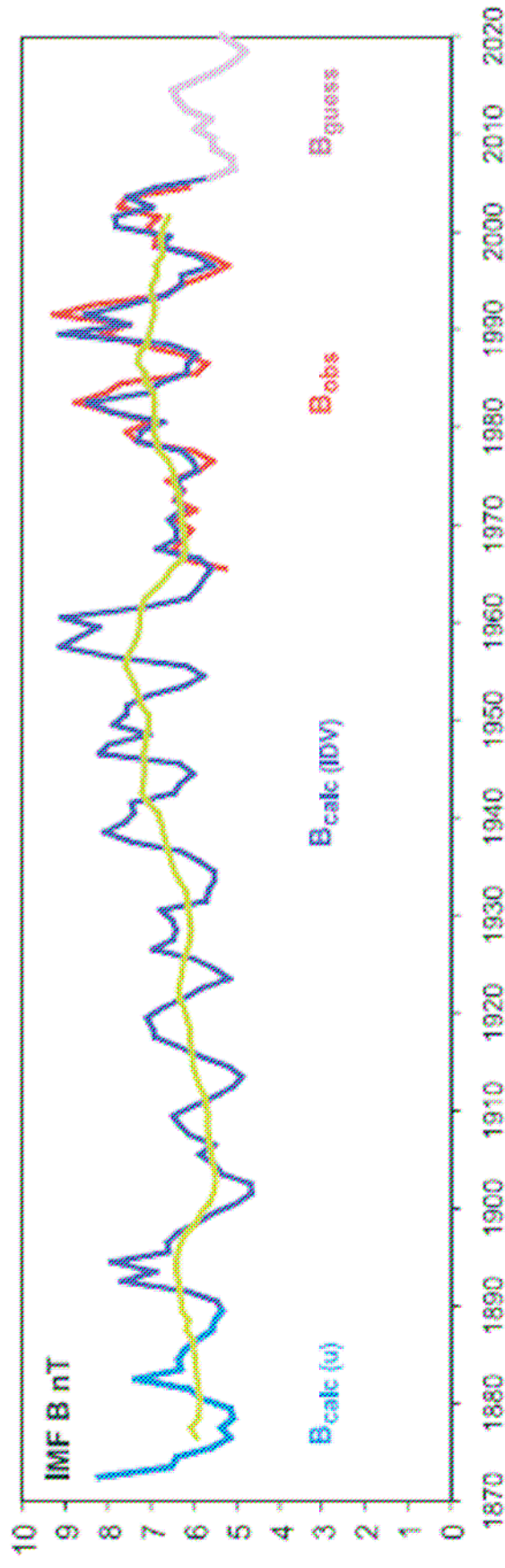


# IDV

- Independent of V
- Strongly-Correlated with B

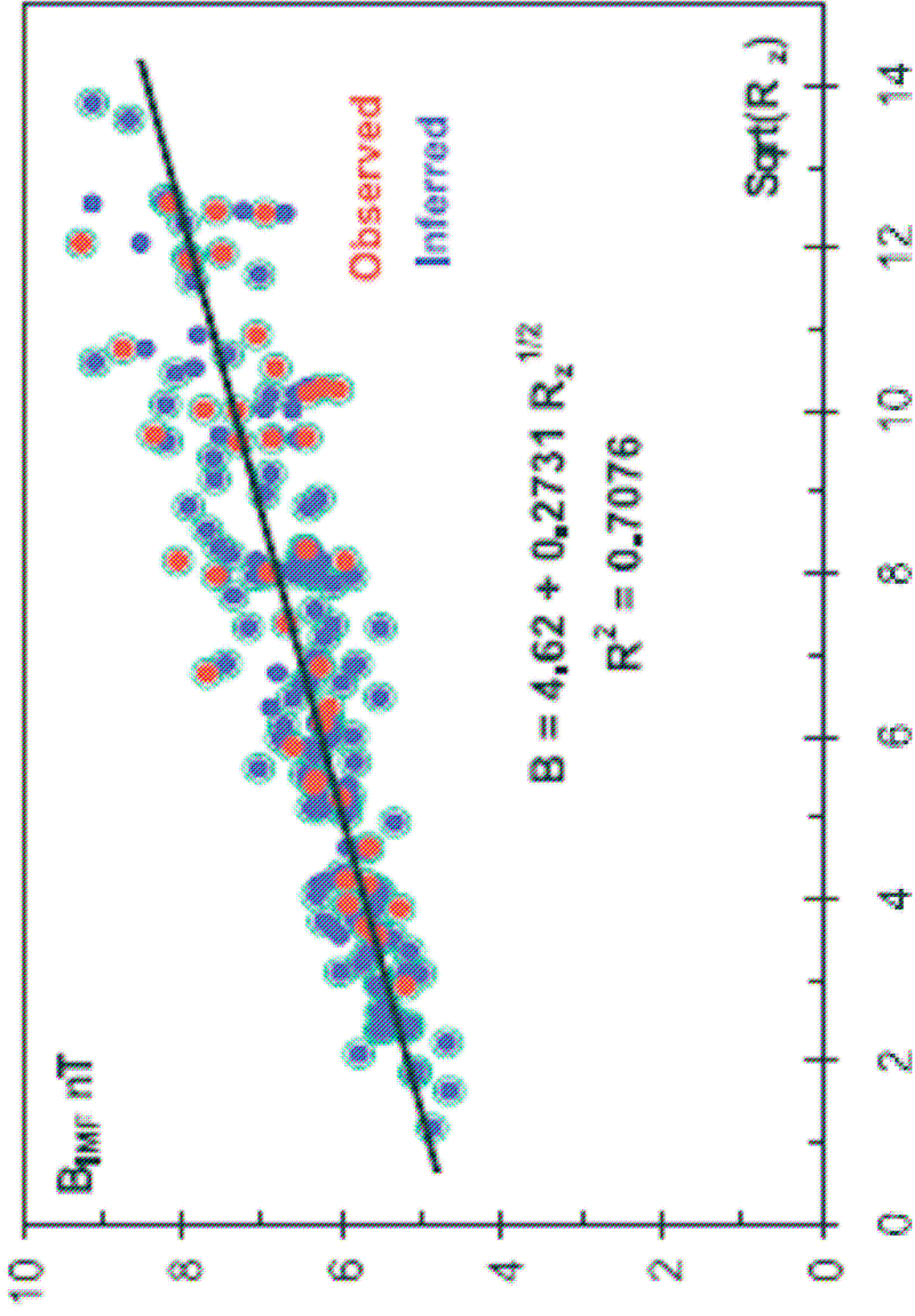


**B since 1872**



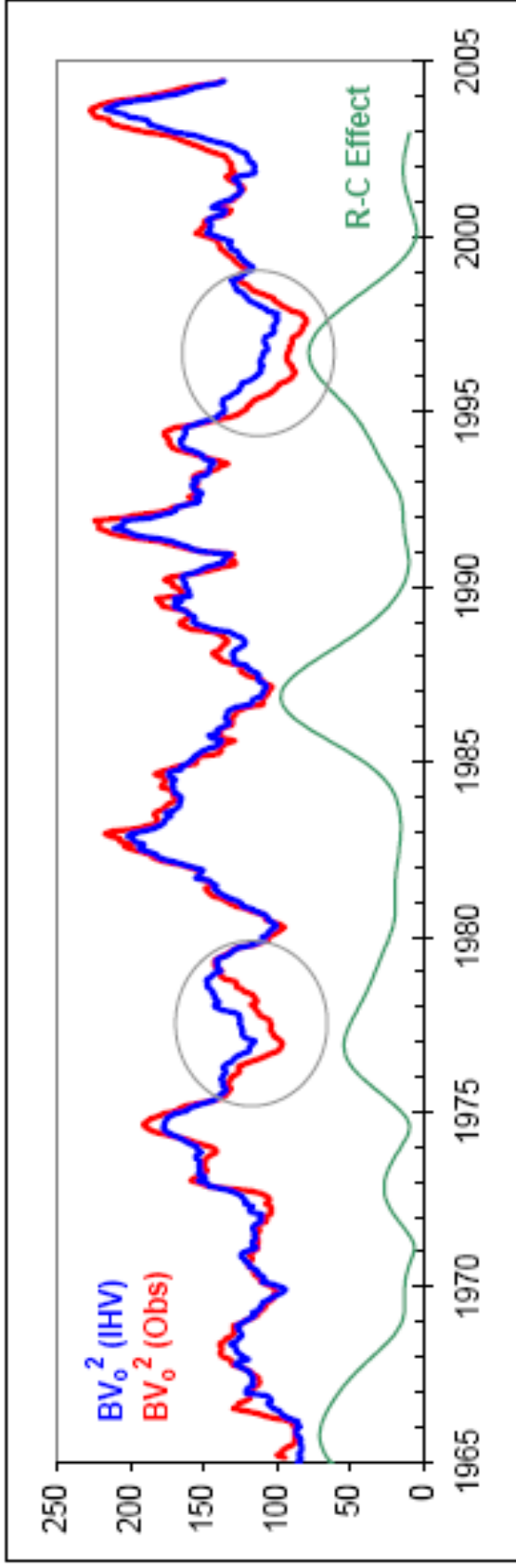
**Svalgaard & Cliver (2005)**

A strong correlation also exists between  
yearly SSN & B



# Interhourly Variability (IHV) Index

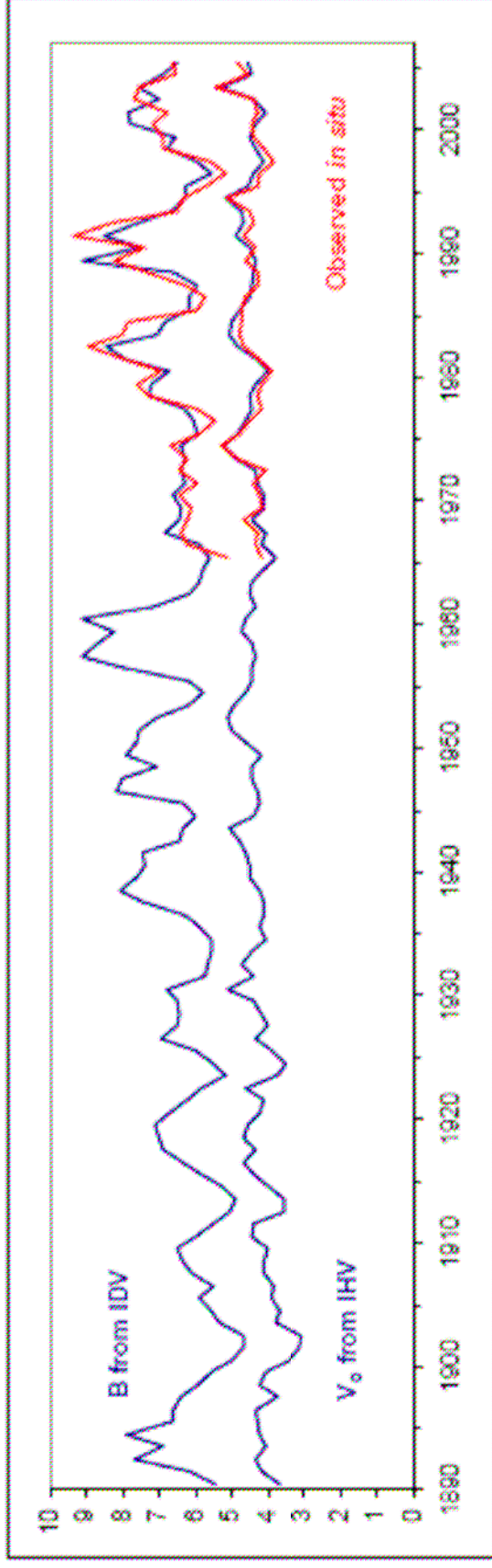
- Recalibrated *aa* index
- Based on local midnight observations for worldwide mid-latitude stations
- Highly-correlated with  $BV^2$





# Two Equations, Two Unknowns

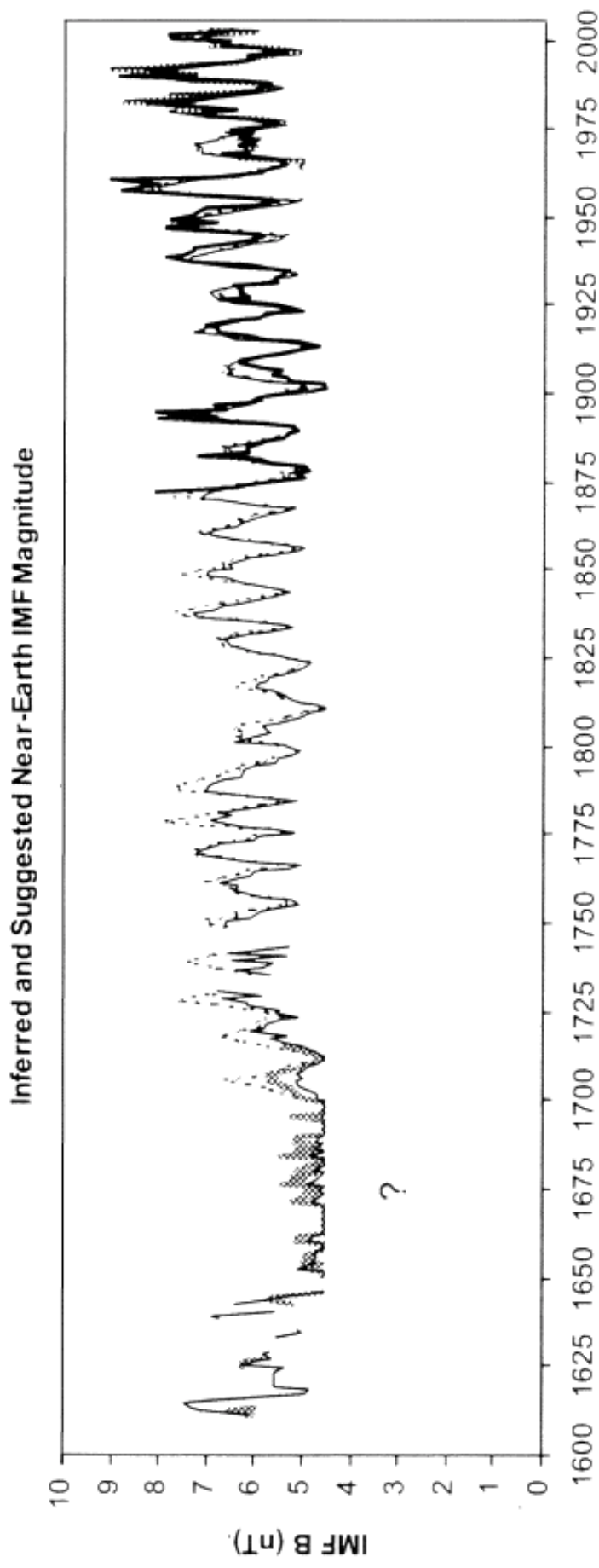
- Solve for  $V(IHV)$
- Compute  $V$  for years before 1965



## Combining

- direct solar wind measurements (1965 - present)
- geomagnetic measurements (1872 - present)
- sunspot observations (1610 - present)

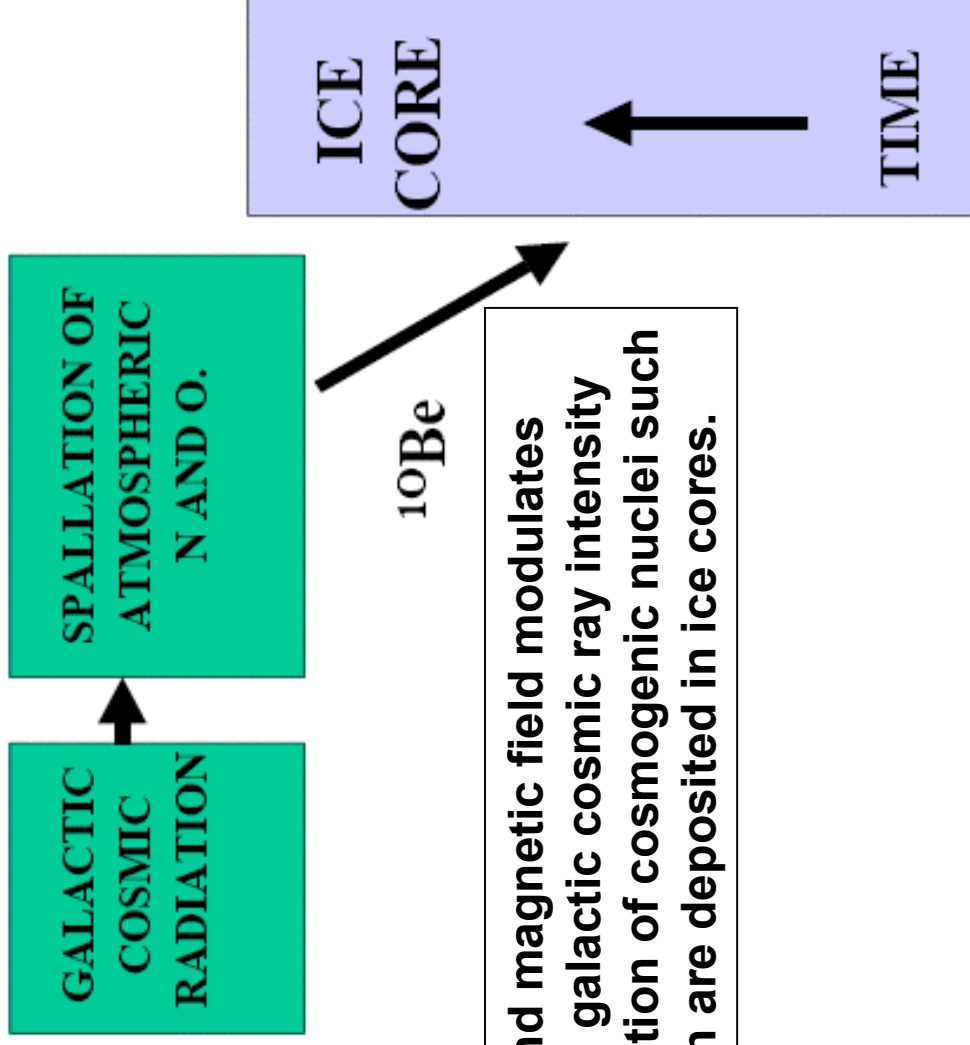
We obtain:



Is it true?

To answer this question, we make consistency checks based on cosmogenic nuclei ( $^{10}\text{Be}$  &  $^{14}\text{C}$ )

# Tutorial on Cosmogenic Nuclei



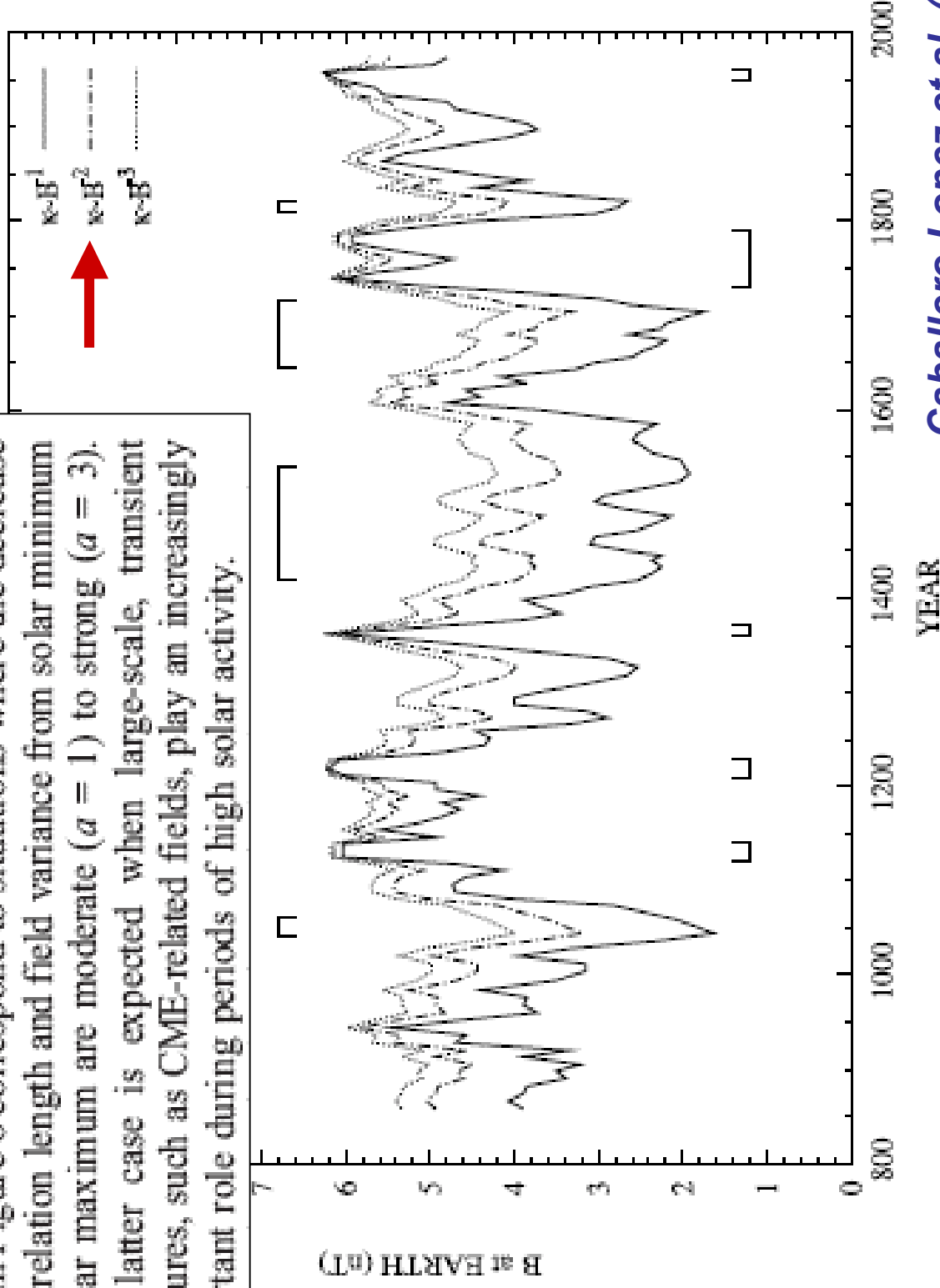
The solar wind magnetic field modulates the incoming galactic cosmic ray intensity & the production of cosmogenic nuclei such as  $^{10}\text{Be}$  which are deposited in ice cores.

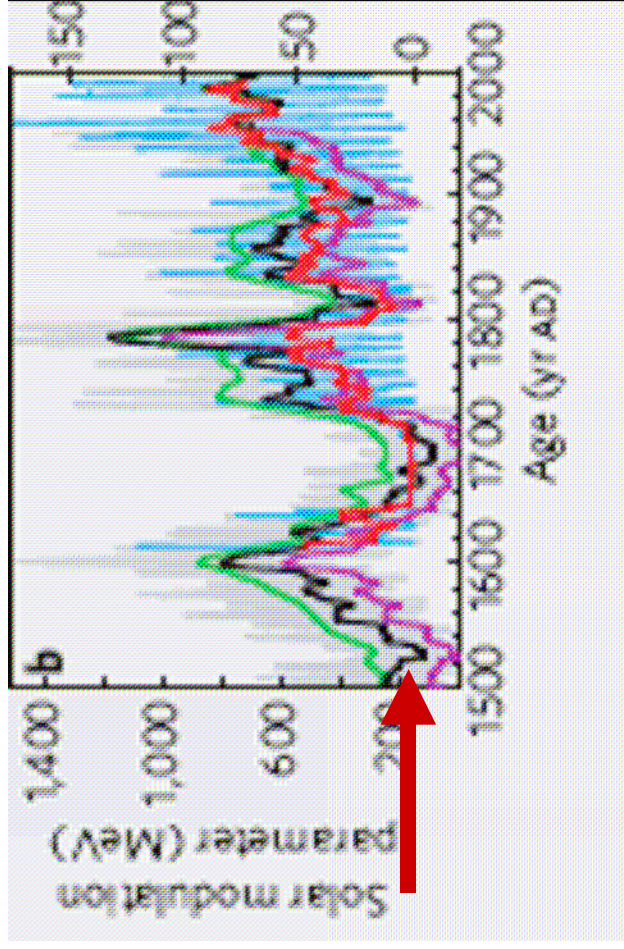
We compared our inferred ~400-yr time-profile of solar wind B with recent determinations of this parameter by

- Caballero-Lopez et al. (2004) ( $^{10}\text{Be}$ )
- Muscheler et al. (2005) ( $^{14}\text{C}$ )

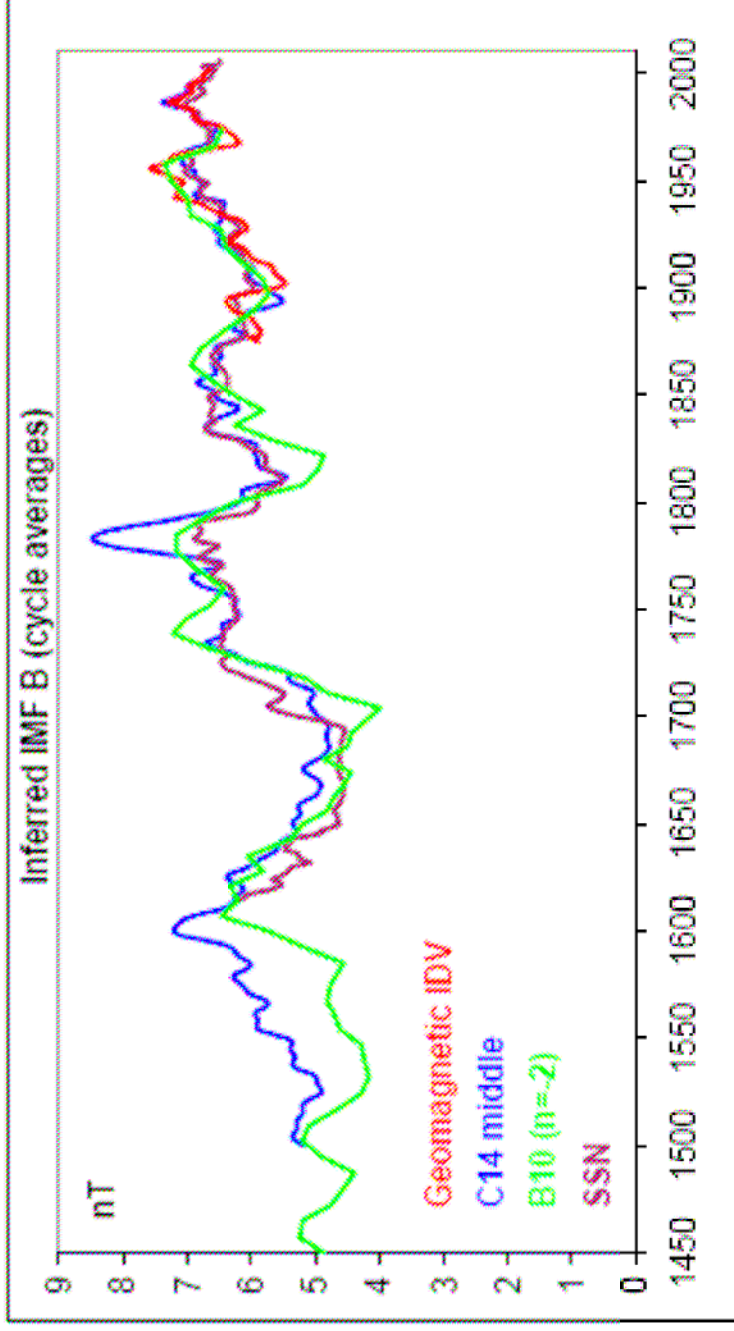
In each case our reconstruction agreed with one of a range of estimates obtained by the above authors. This, in itself, does not guarantee that our inferred time history of B is correct. That said, and model uncertainties aside, we are able to state that our reconstruction is consistent with available evidence to date.

[44] The greatest uncertainty in the estimates of the HMF is due to our present uncertainty of the dependence of  $\kappa$  on  $B$ . As was shown for the  $\kappa \propto B^{-a}$  relationship, the three lines in Figure 6 correspond to situations where the decrease in correlation length and field variance from solar minimum to solar maximum are moderate ( $a = 1$ ) to strong ( $a = 3$ ). This latter case is expected when large-scale, transient structures, such as CME-related fields, play an increasingly important role during periods of high solar activity.





# Reconstructions of Solar Wind B



**“Floor” in Solar Wind B of ~4.5 nT**



## **Conclusions**

- **Reconstruction of Solar Wind B to ~1600**
- **Reconstruction of Solar Wind V to ~1870**
- **Inferred Solar Wind During Grand Minima**
  - **B = ~4.5 nT**
  - **V = ~300 km/s (inferred from 1901)**